

# On external shock model to explain the high-energy emission: GRB 940217, GRB 941017 and GRB 970217A

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**Abstract.** We present a leptonic model on the external shock context to describe the high-energy emission of GRB 940217, GRB 941017 and GRB 970217A. We argue that the emission consists of two components, one with a similar duration of the burst, and a second, longer-lasting GeV phase lasting hundred of seconds after the prompt phase. Both components can be described as synchrotron self-Compton emission from a reverse and forward shock respectively. For the reverse shock, we analyze the synchrotron self-Compton in the thick-shell case. The calculated fluxes and break energies are all consistent with the observed values.

**Keywords:** Gamma-ray burst, Non-thermal radiation

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## INTRODUCTION

General hadronic and leptonic interpretations have been widely discussed to explain photons with energies  $\geq 100$ -MeV. On hadronic models,  $\gamma$ -ray radiation components have been explained by photo-hadronic interactions [1, 2]. On leptonic models, high-energy gamma-ray components have been interpreted by Inverse Compton [3, 4] and synchrotron self-Compton (SSC) [5, 6, 7, 8]. In particular, Fraija et al. (2012) and Sacahui et al. (2012) showed that the short MeV and long-lasting GeV high-energy components presented in GRB 980923 and GRB 090926A respectively, could come from SSC emission in external shocks. In this work we apply the same model in GRB 940217, GRB 941017 and GRB 970417A to describe their high-energy components, and by introducing standard values for the input parameters, we obtain break energies, fluxes, duration, etc in agreement with the observed values. A brief description of the high-energy emission for the considered bursts is given following. The first burst, GRB 940217 is one of the longest and also the most energetic burst. It was detected by the Compton Telescope (COMPTEL), the Energetic Gamma-Ray Experiment Telescope (EGRET) and Interplanetary Network (Ulysses/Burst and Transient Source Experiment, BATSE). The EGRET spark-chamber recorded 10 photons while the main emission was in progress. Following this, an additional 18 photons were recorded for  $\sim 5400$  s, including an 18-GeV photon  $\sim 4500$  s after the main emission had ended. The total fluence above 20 keV was  $(6.6 \pm 2.7) \times 10^{-4}$  erg cm $^{-2}$ , as observed by BATSE large area detectors[9]. The second burst, GRB 941017 was the first burst with clearly evidence of a high energy component different to the usual band function [10]. Analysis of combined

data from two detectors of the Compton observatory, BATSE's LAD and EGRET-TASC, was made to obtain the prompt spectra in an energy range between 30 keV to 200 MeV. This high energy component lasted longer than the burst  $T_{90} = 77s$  and it was described with a photon index of  $\sim -1$  extending up to 200 MeV, and had a fluence above 30 keV of  $6.5 \times 10^{-4} \text{ erg cm}^{-2}$ , which is more than three times that estimated from the BATSE energy range alone. It did not exhibit an energy cut-off, suggesting that even more energy was emitted above 200 MeV. The third and the last burst to consider, GRB 970417a was the burst (of 54 in the field of view) for which the Milagrito collaboration reported marginal evidence of TeV emission during the duration of the burst. BATSE determined the burst position to be R.A. =  $295.7^\circ$ , decl. =  $55.8^\circ$  and its detection was relatively weak with a fluence in the 50 - 300 keV energy range of  $1.5 \times 10^{-7} \text{ ergs/cm}^2$  and  $T_{90}$  observed with BATSE of 7.9 s.

## EXTERNAL SHOCK MODEL

We have considered a leptonic model, where electrons are accelerated in external shock (forward and reverse shocks). This external shock also generates magnetic fields [11]. However, unlike the forward shock emission that continues later at lower energy, the reverse shock emits a single burst in the  $\gamma$ - or X-ray band. The difference between our formalism and previous ones is that, we describe in a unified way ( $\mathcal{R}_B, \mathcal{R}_e, \mathcal{R}_x, \mathcal{R}_M$ , see [8]) the high-energy emission through a superposition of SSC processes from forward and reverse shocks. We summarize the model below. GRB emission is produced when an expanding relativistic shell interacts with the circumburst medium producing forward and reverse shocks. In each shock the constant fractions  $\epsilon_{e,f/r}$  and  $\epsilon_{B,f/r}$  of the shock energy go into electrons and the magnetic field respectively. For the forward shock, we assume that electrons are accelerated to a power-law distribution of Lorentz factor  $\gamma_e$  with a minimum Lorentz factor  $\gamma_m : N(\gamma_e) d\gamma_e \propto \gamma_e^{-p} d\gamma_e$  with  $\gamma_e \geq \gamma_m$  and  $\gamma_m = \epsilon_{e,f}(p-2)/(p-1)m_p/m_e\gamma_f$ , where  $\epsilon_{B,f} = B_f^2/(32\pi\gamma_f^2\eta_f m_p)$  and  $\epsilon_{e,f} = U_e/(4\gamma_f^2\eta_f m_p)$  are the magnetic and electron equipartition parameters respectively,  $\gamma_f$  is the Lorentz factor of the bulk and  $\eta_f$  is the ISM density. Given the cooling electron Lorentz factor  $\gamma_{e,c} = 3m_e(1+z)/(16\epsilon_{B,f}\sigma_T m_p t_{d,f}\Gamma_f^3\eta_f)$  and the deceleration time  $t_{d,f}$ , the break energies of the photons radiated by electrons at a distance  $D$  from the source in natural units ( $c=\hbar=1$ ) are given by,

$$E_{m,f} \sim \frac{2^{5/2} \pi^{1/2} q_e m_p^{5/2} (p-2)^2}{m_e^3 (p-1)^2} (1+z)^{-1} \epsilon_{e,f}^2 \epsilon_{B,f}^{1/2} n_f^{1/2} \gamma_f^4$$

$$E_{c,f} \sim \frac{\pi^{7/6} 3^{4/3} m_e q_e}{2^{13/6} m_p^{5/6} \sigma_T^2} (1+z)^{-1} (1+x_f)^{-2} \epsilon_{B,f}^{-3/2} n_f^{-5/6} E^{-2/3} \gamma_f^{4/3}$$

where  $E$  is the isotropic energy. The SSC break energies ( $E_{m,f}^{(IC)} \sim \gamma_m^2 E_{m,f}$  and  $E_{c,f}^{(IC)} \sim \gamma_c^2 E_{c,f}$ ) are also given by[7],

$$E_{m,f}^{(IC)} \sim \frac{6 q_e m_p^{15/4}}{2^{5/4} (3\pi)^{1/4} m_e^5} (1+z)^{5/4} \epsilon_{e,f}^4 \epsilon_{B,f}^{1/2} n_f^{-1/4} E^{3/4} t_f^{-9/4}$$

$$E_{c,f}^{(IC)} \sim \frac{2^{3/4} 27 \pi^{7/4} q_e m_e^3}{128 3^{1/4} m_p^{9/4} \sigma_T^4} (1+z)^{-3/4} (1+x_f)^{-4} \epsilon_{B,f}^{-7/2} n_f^{-9/4} E^{-5/4} t_f^{-1/4}$$

On the other hand, when the reverse shock crosses the shell it heats up and accelerates electrons. Considering the thick shell case, when the ejecta is significantly decelerated, the synchrotron

$$E_{m,r} \sim \frac{4 \pi^{1/2} q_e m_p^{5/2} (p-2)^2}{m_e^3 (p-1)^2} (1+z)^{-1} \epsilon_{e,r}^2 \epsilon_{B,r}^{1/2} \Gamma_r^2 n_r^{1/2}$$

$$E_{c,r} \sim \frac{9 \pi 2^{1/2} m_e q_e}{8 (3^{1/2}) m_p \sigma_T^2} (1+z)^{-1/2} (1+x_r+x_r^2)^{-2} \epsilon_{B,r}^{-3/2} n_r^{-1} E^{-1/2} T_{90}^{-1/2}$$

and SSC break energies are given by [8, 12],

$$E_{m,r}^{(IC)} \sim \frac{2^{21/4} \pi^{3/4} m_p^{13/4} (p-2)^4}{3^{1/4} m_e^5 (p-1)^4} (1+z)^{-7/4} \epsilon_{e,r}^4 \epsilon_{B,r}^{1/2} \Gamma_r^4 n_r^{3/4} E^{-1/4} T_{90}^{3/4},$$

$$E_{c,r}^{(IC)} \sim \frac{3^{7/2} \pi m_e^3 q_e}{2^{11} m_p^3 \sigma_T^4} (1+z)^{3/2} (1+x+x^2)^{-4} \epsilon_{B,r}^{-7/2} n_r^{-3} E^{-1/2} \Gamma_r^{-6} T_{90}^{-5/2},$$

where  $T_{90}$  is the burst duration. A detailed description of the model is given in Fraija et al. (2012) and Sacahui et al. (2012).

## RESULTS AND CONCLUSIONS

We use typical [8, 12, 13] values (table 1) for  $\epsilon_{B,r}$  and  $\epsilon_{B,f} \sim (10^{-4} - 10^{-3})$  which in comparison with previous works on GRB 980923 and GRB 090926A, do not require to be different,  $\epsilon_{e,r} \neq \epsilon_{e,f} \sim (0.1 - 0.9)$ . Also,  $\eta_f \leq \eta_r \sim 10 \text{ cm}^{-3}$ ,  $\gamma_f \sim 600$  and  $\gamma_r \sim 1000$ . The calculated and observed quantities are given in Table 2. In this letter, we present a leptonic model based on external shocks to describe the high-energy emission for GRB 940217, GRB 941017 and GRB 970217A. Clearly the observations for the considered bursts are less restrictive than those for GRB 980923 and GRB 090926A [7, 8]. To describe the high energy component in GRB 940217 and GRB 970417A was only required SSC emission from forward shock and while for GRB 941017, the high component  $\geq 200$  MeV was a superposition of SSC emission from forward and reverse shock in the thick shell case. Unlike of GRB 980923 and GRB 090926A, was not required the magnetization of the jet. This may be a consequence of the lack of keV-MeV emission to constrain the emission from the reverse shock. We note that there could be some bursts with emission at energies up to a few TeV, which would

be candidates to be detected by observatories with wide-field of view as HAWC[14].

GRBs	940217	941017	970217A
Forward shock			
$\epsilon_{B,f}$	$10^{-3}$	$10^{-3}$	$10^{-4}$
$\epsilon_{e,f}$	0.3	0.1	0.5
$n_f$ ( $cm^{-3}$ )	1	10	1
$\gamma_f$	600	600	600
Reverse shock			
$\epsilon_{B,r}$	$10^{-3}$	$10^{-3}$	$10^{-4}$
$\epsilon_{e,r}$	0.5	0.9	0.5
$n_r$ ( $cm^{-3}$ )	10	10	10
$\gamma_r$	1000	1000	600

**Table 1. Parameters used.**

GRBs	940217	941017	970417A
Quantities	calculated (observed)	calculated (observed)	calculated (observed)
Forward shock			
$E_{m,f}$ (keV)	128.9 ( - )	45.3 ( $\sim 100$ )	169.8 ( $\sim 100$ )
$E_{c,f}$ (eV)	0.12 ( - )	111.3 ( - )	512 ( - )
$E_{m,f}^{(IC)}$ (GeV)	33.13 ( $\sim 10$ )	1.8 ( $\geq 0.2$ )	$8.6 \times 10^3$ (1)
$E_{c,f}^{(IC)}$ (eV)	$3.8 \times 10^{-11}$ ( - )	$1.5 \times 10^3$ ( - )	885.2 ( - )
Duration of the component (s)	1000 ( $\sim 5600$ )	150 ( $\geq 120$ )	100 ( $\sim 100$ )
$(\nu F_{\nu max})^{SSC}$ ( $erg\ cm^{-2}\ s^{-1}$ )	$2.95 \times 10^{-7}$ ( $\sim 10^{-7}$ )	$3.74 \times 10^{-6}$ ( $\sim 10^{-6}$ )	$1.85 \times 10^{-5}$ ( $\sim 10^{-5}$ )
Reverse shock			
$E_{m,r}$ (eV)	0.09 ( - )	28.3 ( - )	8.7 ( - )
$E_{c,r}$ (eV)	1.5 ( - )	9.8 ( - )	2.93 ( - )
$E_{m,r}^{(IC)}$ (MeV)	$1.3 \times 10^{-3}$ ( - )	386.5 ( $\geq 200$ )	13.1 ( - )
$E_{c,r}^{(IC)}$ (eV)	152.9 ( - )	386.5 ( - )	849.2 ( - )
$(\nu F_{\nu max})^{SSC}$ ( $erg\ cm^{-2}\ s^{-1}$ )	$1.8 \times 10^{-7}$ ( - )	$1.58 \times 10^{-6}$ ( $\sim 10^{-6}$ )	$8.8 \times 10^{-6}$ ( - )

**Table 1. Calculated quantities using the model described in the text. When available, the observed values are given.**

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